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RESEARCH PAPER

Performance, Capability and Costs of Small-Scale Cable Yarding Technology

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Abstract The authors tested two mini-yarders, one for uphill and the other for downhill extraction. The two machines were modern commercial models, offering state-of-the-art yarding technology on a miniature scale and at a much lower cost than required for purchasing a full-size tower yarder. The two units must not be regarded as alternative, but rather as complementary, since they offer different capabilities and advantages. Both machines were tested while harvesting firewood from the thinning of young beech stands in Central Italy. The tests indicated that both units can reach a productivity between 1.5 and 2.4 m^3 SMH^{-1}, including all delays, as well as set-up and dismantle time. Calculated extraction cost ranged between 24 and over 30€ m^{-3}. The authors calculated a set of regression equations for estimating machine productivity as a function of the main work conditions. The performance of the studied mini-yarders does not seem much inferior to that achieved by professional light tower yarder under the same work conditions, but the lighter construction of the small-scale units may result in a lower resistance to wear and abuse. In any case, mini-yarders seem ideal for deployment under the typical conditions of small-scale forestry, offering a good solution to wood extraction on steep terrain, competitive with animal and winch logging in terms of productivity, cost and operator comfort.

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Introduction

Non-industrial private forestry (NIPF) does not fit smoothly into the modern commodity chain, which may put owners at an economical disadvantage, despite the many positive attributes of small-scale forestry (Bliss and Kelly 2008). This also reflects on the active management of NIPF, which recent studies have shown to be technically inefficient (Lien et al. 2007). In the light of increased global competition, which is imposing a growing strain on all commercial activities, including wood harvesting, forest operations must increase their productivity, while decreasing production costs (Hoesch 2003). Increasing efficiency in the forestry-wood chain is one of the main policies to support forestry entrepreneurship (Niskanen et al. 2007). The problem is that NIPF ownerships are often too small for cost-effective mechanized harvesting (Kittredge et al. 1996), whose overall cost-efficiency is heavily affected by the fixed cost of moving the operation to the worksite (Väätäinen et al. 2006). Small tree size often compounds this problem, calling for appropriate system design and equipment selection (Lyon et al. 1987). Much work has been devoted to developing cost-effective harvesting systems for small-scale forestry, leading to the design of dedicated light-weight, low-cost and fully-mechanized operations (Becker et al. 2006). Together with the many ingenious adaptations of the ubiquitous farm tractor, these systems are only viable on gentle terrain, and cannot perform safely and effectively on steep terrain (De Lasaux et al 2009). When slope gradient exceeds 30 %, traditional small-scale harvesting technology can only offer winches, animal power and gravity sliding. Although animal power can still be competitive under the appropriate conditions (Wang 1997), its widespread application is hardly compatible with the lifestyle of industrialized countries, as demonstrated by the rapidly shrinking number of animal loggers in western Europe and North America (Toms et al. 2001) and by the low utilization of existing operations (Shresta et al. 2005). On the other hand, winching can produce acceptable results on very short distances only (Zeĉić et al. 2005), and gravity sliding requires a high labour input (Eroglu et al. 2007). Cable yarding would offer a much better solution, if it was not for the small size characterizing both NIPF sales and the logging operations that have adapted to the NIPF source (Rickenbach and Steele 2006). However, the market is currently offering downsized cable yarding set-ups especially designed for small-scale users: such miniature plants are only suitable for small trees, but carry only a fraction of the capital cost that must be paid for a full-size yarder, while adopting state-of-the art technology. If functional, these units may provide a cost-effective solution to the harvesting of small trees from NIPF holdings in steep terrain. The goal of this study was therefore to explore the potential of these new systems by determining their productivity, operating cost, payload capacity and extraction distance range.

Materials

The study focused on two different commercial units, considered as representative of the main options offered by the mini-yarder category and regarded as complementary units to be used under different work conditions, rather than as competitors for the same job type.

Unit one was based on a semi-automatic carriage and a modified forestry winch, designed for application to any farm tractor capable of delivering at least 35 kW at the power-take-off (PTO). The unit was designed for installation in the gravity skyline configuration only. The skyline was a steel wire rope with a diameter of 14 mm and was to be tightened with a hand-hoist between two robust trees, acting as end-spars. The winch mainline was attached to the carriage and used to move the carriage back and forth along the supporting skyline, and also to hoist the loads once the carriage had reached the loading point. Two blocks were placed on the skyline to stop the carriage, respectively at the loading and the unloading points. The blocks could slide along the skyline until the appropriate points were located, and then clamped on the cable by built-in hydraulic clamps activated with a manual pump. This system could only be used for yarding uphill and towards the winch, and had a nominal maximum payload of 1.5 metric tonnes. Its maximum technical range depended on the capacity of the mainline drum, normally around 200 m. Controls were very simple, consisting of a clutch and a brake located near the main winch, and activated manually by the winch operator. Although comparatively simple, this unit was more advanced of any of the basic tackle-block carriage set-ups. The approximate price was in the range of 20,000€, excluding the tractor. Unit one is manufactured in Austria and traded under the commercial name of Savall 1500 (www.interforst.at).

Unit two was a miniature version of the newest motorized self-propelled carriages popular in Europe (Stampfer et al. 1998). The set-up only consisted of the motorized carriage and a 10 mm compacted steel wire rope skyline. As in the previous case, the skyline was to be tightened between two robust trees, using a hand-hoist or an old tractor. The carriage had a weight of 200 kg and contained a 7 kW petrol engine, a hydraulic pump and 4 hydraulic motors. The engine powered the pump, which delivered hydraulic flow and pressure to the three motors moving the friction pulleys. These pulleys enveloped the skyline and could generate enough traction to pull the loaded carriage along the tight cable. The fourth hydraulic motor powered the winch hoist, equipped with 50 m of 5 mm Dyneema rope and capable of lifting up to 450 kg. This unit could yard uphill, downhill and on flat terrain, but it was best suited to downhill yarding, due to the limited power of its small petrol engine. Both the operator at the loading and at the unloading point could command the carriage through a couple of radio-controls, capable of activating carriage translation and hoist operation (drop-line pay-out and reel-in). The radio-controls were mutually exclusive, so that the operator currently commanding the carriage had to activate his colleague’s remote by stopping the carriage and de-activating his own remote, which the carriage would signal with a loud beep. Only after that could the other operator assume control of the carriage. This was done in order to avoid dangerous interference. The maximum technical range of this system is theoretically

unlimited, but the low carriage speed and payload weight suggest keeping the extraction distance within the 200 m limit. The purchase price of the unit is approximately 16,000€, all included. Unit two is manufactured in Italy and traded under the commercial name of Vallauri Miniliner (www.vallauri.net).

The main characteristics of both units are described in Table 1. At this stage, it is important to stress that the two units did not represent two alternatives for the same job type, but rather two complementary operations, one for uphill and the other for downhill yarding. This is very important, because until present, mini-yarder technology only allowed for effective uphill yarding. The few units also allowing for downhill yarding resorted to impractical devices, which made it possible to yard downhill, but always keeping the winch on the upper end of the line. Before the appearance of the motorized mini-yarder, no other small-scale yarding unit allowed for yarding downhill and keeping the operation to the lower end of the line. Hence the interest of this study, which analyzes the two main options for yarding with small scale equipment, respectively uphill to an upper landing (unit one) and downhill to a lower landing (unit two). Both set-ups offer the advantages of low investment cost, simple construction and easy maintenance, which increase their potential for deployment in industrialized and developing countries alike, and wherever finance represents a main constraint to the modernization of NIPF management (Dubey 2008).

Study Sites

The study was conducted in two beech (*Fagus sylvatica L.*) forests in the Apennine mountain range, in Central Italy. Both stands were young high-forests, derived from the conversion of abandoned beech coppice. Coppice represents about 50 % of the Italian forest surface, and beech is the most common species in the mountains above the altitude of app. 1,000 m. Due to poor accessibility, mountain coppice is often abandoned, which justifies the general policy towards its conversion to high forest (Cantiani and Spinelli 1996). This is generally obtained through repeated thinning, aimed at fostering the best specimen while keeping a dense enough cover to prevent stool resprouting. Although successful in reducing the intensity of management, conversion cannot solve the technical problems posed by steep terrain, which complicate its cost-effective application. Harvesting is generally conducted according to the short-wood method, where logs are manufactured in the stand and extracted by sliding, winching or hauling with pack mules (Baldini and Spinelli 1987). These operations yield exclusively firewood logs, a typical product of small-scale forestry, often integrated into local supply and consumption chains (Hartter and Boston 2008).

The two plots selected for the study are described in Table 2 and are representative of the two main cases described above: plot one was located downhill from the main access trail, so that the wood was yarded uphill with unit one, whereas plot two was uphill of the main trail and the wood was yarded downhill with unit two. The two plots were located in two different places because the actual tests were sponsored by two distinct regional agencies. The two stands

Table 1 Description of the test sites

Placename	Forca di Gualdo	Poggio Moscona
Latitude	42°51′33.19″ N	44°01′48.70″ N
Longitude	13°11′17.85″ E	10°59′16.67″ E
Municipality	Castel S.Angelo s/Nera	Pistoia
Province	Macerata	Pistoia
Surface (ha)	0.29[a]	0.38
Elevation (m a.s.l.)	1,425–1,495	1,159–1,255
Species	*Fagus sylvatica* L.	
Average age (years)	80	68
Treatment	Thinning	Thinning
Type	Selection	Selection
Criterion	From below	From below
Intensity (% number)	48	30
Removal		
Number (trees ha^{-1})	409	276
DBH (cm)	17.4	19.7
Height (m)	14.6	19.7
Firewood (m^3 ha^{-1})	87	69
Wood and site characteristics		
Wood density (kg m^{-3})	1,091	960
Moisture content (%)	42.0	38.7
Slope gradient (%)	60	52
Terrain class[b] (code)	2.2.5	2.2.5

[a] Excluding the 50-m deep untouched screen nearest to the road

[b] According to UK Forestry Commission (1995)

were quite similar, and the operators performing the work were the same in both tests. All operators had at least 5 years of experience with cable yarding and they were all in the 35–45 years age class. No attempt was made to normalize individual performances by means of productivity ratings (Scott 1973), recognizing that normalization or corrections can introduce new sources of errors and uncontrolled variation in the data material (Gullberg 1995). The authors believe that the selected operators were representative of the professional, expert and motivated workforce needed for the efficient operation of modern equipment.

About 25 m^3 of wood were yarded at each site. The operation on plot one was designed to extract whole trees for later processing at the landing, whereas that on plot two extracted 2-m long logs manufactured in the stand. Normally, the skyline of mini-yarders has a limited ground clearance and runs at 5–15 m from the soil profile, implying that whole trees cannot be fully suspended during extraction. The yarding of semi-suspended trees is only compatible with uphill extraction: when used for downhill extraction it results in a very “jerky” ride, due to the natural tendency of the load to slide downhill. That explains why test two was conducted on short logs, this being the most appropriate work technique for the specific case. As a

Table 2 Description of the mini-yarders

Placename	Forca di Gualdo	Poggio Moscona
Unit (*n*)	1	2
Model	Savall 1500	Miniliner
Skyline drum capacity (m)	300	300
Skyline diameter (mm)	14	10
Skyline tension (kg)	2,500	2,000
Mainline drum capacity (m)	300	–
Mainline diameter (mm)	8	–
Mainline max. pull (kg)	5,000	–
Drop-line drum capacity (m)	–	50
Drop-line diameter (mm)	–	5
Drop-line max. pull (kg)	–	450
Carriage type	Semiautomatic	Self-propelled
Carriage load capacity (kg)	1,500	500
Carriage engine power (kW)	Tractor PTO	7
Carriage weight (kg)	80	200
Radiocontrol	No	Yes

consequence, unit two was manned by three operators, one at the unloading point and two at the loading point for stacking and pre-choking the logs. Unit one was manned by two operators only, since one man alone was able to hook the loads. Most loads were one or two trees. In this case, the third member of the crew operated a mini-processor stationed at the roadside, for picking up incoming loads and mechanically processing them into 2-m long firewood logs. This, however, was a distinct work stage, different from yarding and not included in this study (Spinelli et al. 2009).

Methods

A time-motion study was carried out to evaluate yarder productivity and to identify those variables that are most likely to affect it. These included extraction distance, lateral yarding distance and payload size (Bergstrand 1991). Each yarding cycle was stop watched individually, using Husky Hunter hand-held field computers running the dedicated Siwork3 time study software (Kofman 1995). Productive time was separated from delay time (Björheden et al. 1995). Yarding distances were determined with a laser range-finder or a cotton-thread hip chain. No correction was made for slope gradient, so that these distances represent the actual paths covered by the carriages. On test one, load size was estimated by measuring the diameter at breast height (DBH) of all trees in each cycle, and converting DBH figures into firewood volumes with the appropriate tariff tables (Nosenzo 2008). For this purpose, a DBH-height curve was built on the measurements taken from 30 sample trees. Load size estimates were much easier in test two, where all the logs

constituting each cycle were individually scaled after measuring their total length and their diameter at mid-length.

Data from individual cycle observations were analyzed with regression technique in order to calculate meaningful relationships between productive time consumption and work conditions, such as yarding distance and load size (SAS 1999).

Machine costs were calculated with the method described by Miyata (1980), on an estimated annual utilization of 500 scheduled machine hours (SMH) and a depreciation period of 10 years. However, the farm tractor powering unit one was depreciated on 1,000 SMH per year, assuming that it could be used in other works besides yarding. Labour cost was set to 15€ SMH^{-1} inclusive of indirect salary costs. These assumptions are meant to reflect the low utilization level typical of small-scale logging, and the comparatively high cost of forestry labour encountered in industrialized countries. The costs of fuel, insurance, repair and service were obtained directly from the operators. The calculated operational cost was increased by 10% to account for overhead costs (Hartsough 2003). Further detail on cost calculation is shown in Table 3.

Results

Table 4 shows the main results obtained from the test. The average net productivity varied between 2.4 and over 4 m^3 per productive machine hour (PMH), and was remarkably higher for unit two, which could produce a turn in slightly more than 3 min. However, actual productivity must integrate delay time, as well as set-up and dismantle time. Such unproductive times accounted for about 40 % of the total scheduled time, reducing actual productivity to 1.5 and 2.4 m^3 SMH^{-1}, respectively for unit one and unit two. The utilization rates determined by our study are not much smaller than those reported by Huyler and LeDoux (1997) for a very popular light tower yarder model. Applying the calculated rates of 50 and 58€ SMH^{-1}, these figures correspond to a yarding cost of 32.7 and 24. 1€ m^{-3}, respectively.

Payload size was in the range of 0.2 m^3 for both units, always much below the rated capacity of the carriages.

Set-up and dismantle time amounted to 4.7 and 2.3 h, respectively for unit one and unit two. Unit one took twice as much time to set-up and dismantle because the test site presented a convex slope profile, which is not very favorable to the installation of a yarder. This imposed a careful selection of the two spar trees, which had to be tall and robust enough for placing the mounting blocks high up on the stem. With its concave slope profile, plot two offered much better conditions: there was no need to place the mounting blocks very high on the spar trees, which made it much easier their selection and rigging.

The table also reports the calculated delay factor for both units. This value represents the quotient of delay time over net cycle time. Finding no correlation between delay types, Spinelli and Visser (2009) showed that it is correct to express delay as a factor, which can be used to derive delay time from productive time. On most operations, net process time can be modeled quite well with a reasonably limited number of data points, whereas the modeling of delays is much more

Table 3 Machine costing: assumptions, cost centers and total cost

Unit (*n*)	1	1	2
Machine (*n*)	Tractor	Savall	Miniliner
Investment cost (€)	35,000	20,000	16,000
Service life (years)	10	10	10
Annual utilization (h)	1,000	500	500
Recovery value (€)	7,000	4,000	3,200
Interest on capital (%)	4	4	4
Fuel consumption (l h^{-1})	2.5	0.0	1.5
Fuel price (€ l^{-1})	1.1	1.1	1.3
Lubricant (% of fuel cost)	30	30	30
Labour cost (€ h^{-1})	15	15	15
Crew (*N*)	0	2	3
Fixed cost			
Depreciation (€ $year^{-1}$)	2,800	1,600	1,280
Interest (€ $year^{-1}$)	896	512	410
Insurance and tax (€ $year^{-1}$)	896	512	410
Yearly fixed cost (€ $year^{-1}$)	4,592	2,624	2,099
Hourly fixed cost (€ h^{-1})	4.59	5.25	4.20
Variable cost			
Fuel (€ h^{-1})	2.77	0.00	1.89
Lubricant (€ h^{-1})	0.83	0.00	0.57
Repair and maintenance (€ h^{-1})	0.84	0.96	1.28
Personnel (€ h^{-1})	0.00	30.00	45.00
Hourly variable cost (€ h^{-1})	4.44	30.96	48.74
Operating cost (€ h^{-1})	9.03	36.21	52.94
Profit and overhead (%)	10	10	10
Profit and overhead (€ h^{-1})	0.90	3.62	5.29
Total operating cost (€ h^{-1})	9.93	39.83	58.23

Cost in Euro (€) as on July 30, 2009

difficult, due to their erratic occurrence pattern. Thus, a practical solution is offered by developing a model for predicting net cycle time and then adding delay time through the application of an appropriate factor. The delay factor for unit two is twice as high as that of unit one, possibly reflecting the higher sophistication of the self-propelled carriage. However, the duration of the study was too limited to confirm whether such difference was statistically significant.

The number of valid observations collected during the tests was large enough to develop reliable models for predicting cycle time. For unit one, outhaul time was strongly correlated (R^2 0.816) to outhaul distance, and the relationship was described by the following equation: $\min^{-100}$ per turn $= -23.938 + 1.001 \times$ distance (m). The same was true for inhaul time, which was also strongly correlated (R^2 0.626) to inhaul distance, according to the following equation: $\min^{-100}$ per turn $= 4.504 + 0.823 \times$ distance (m). Loading time rapidly increased with lateral

Table 4 Productivity and cost: summary table

Placename	Forca di Gualdo	Poggio Moscona
Unit (type)	Savall	Miniliner
Line length (m)	140	115
Extraction distance (m)	118	67
Turns (*n*)	125	115
Harvest (m^3)	25.2	26.0
Harvest density (m^3 m^{-1})	0.18	0.23
Avg. load size (m^3 $turn^{-1}$)	0.202	0.226
Work time (h)	10.44	6.27
Delay time (h)	1.04	1.37
Preparation time (h)	0.38	0.76
Set-up & dismantle (h)	4.73	2.38
Total time (h)	16.60	10.78
Utilization (%)	62.9	58.2
Delay factor (delays $work^{-1}$)	0.10	0.22
Cycle time (Net min $turn^{-1}$)	5.01	3.27
Productivity (m^3 PMH^{-1})	2.42	4.15
Productivity (m^3 SMH^{-1})	1.52	2.42
Hourly cost (€ SMH^{-1})	50	58
Unit cost (€ m^{-3})	32.7	24.1

Harvest density = m^3 of wood harvested divided line length; Utilization = work time divided total time; *PMH* productive machine hour, i.e. work time excluding delays; *SMH* scheduled machine hour, i.e. worksite time including all delays

distance, as described by the quadratic relationship: min^{-100} per turn = 226.815–8.879 × Lateral distance (m) + 0.540 × Lateral distance^2 (m). The correlation coefficient R^2 here was 0.601. Unloading time was a constant, equal to 45.5 min^{-100} per turn. Similar relationships described the functions of unit two. In particular, outhaul time in min^{-100} per turn was modeled by the equation = 0.53 + 1.514 × distance (m), with a 0.950 R^2; inhaul time in min^{-100} per turn was equal to 6.026 + 1.043 × distance (m), and had a 0.901 R^2; loading time increased linearly with lateral distance according to the relationship: min^{-100} per turn = 62.848 + 4.665 × Lateral distance (m), which had a correlation coefficient R^2 of 0.436. Finally, unloading time was a constant, equal to 49.4 min^{-100} per turn. These equations estimated net cycle time, excluding unproductive delays, which averaged 10 and 22% of net cycle time, respectively for unit one and two.

All regression equations had high statistical significance (*P*-values <0.05) and could explain most of the variability in the data pool, as shown by a coefficient of determination often higher than 0.8. The lowest R^2 values were recorded for loading time: here lateral yarding distance was the main independent variable, but this variable alone could not account for the characteristics of the individual load paths, with their higher or lower presence of obstacles such as rocks, stumps or residual trees. Clearing such obstacles could take some work, affecting the overall time consumption in the loading phase. However, it was quite difficult to develop an

objective way of accounting for the presence of obstacles, and therefore their effect could not be included in the regression as an independent variable. Yarding distance seemed to be the main variable affecting time consumption, whereas load size had little effect, at least within the range of observed values.

The equations described above were used to calculate productivity as a function of yarding distance, for the average load actually yarded by each unit and an assumed lateral yarding distance of 15 m. The results are shown in Fig. 1, which reports the productivity of both units, calculated by including all delay time except for the time taken by preparation, set-up and dismantling. Under the same yarding distance, both units achieve very similar productivity levels, with unit one performing slightly better than unit two over distances longer than 70 m, whereas the contrary is true for any distance shorter than that.

Discussion and Conclusion

Overall, unit two performed better than unit one, recording faster cycles and a shorter set-up and dismantle time. Faster operation may depend on the extra crew member assisting loading, on the easier handling of short logs and especially on the shorter extraction distance. Due to the aesthetic concerns of the owner, harvest trees in plot one were selected further away from the road, leaving a 50 m deep untouched screen near the road. No such concerns were demonstrated by the owners of plot two, allowing for an evenly distributed harvest. The technical result is that unit two harvested loads at an average yarding distance that was about 40 % shorter than that covered by unit one.

Figure 1 shows that under the same distance, the two units reached very similar productivity levels. Unit one was faster than unit two, and offered a slightly better performance on longer yarding distances. This is probably related to the higher

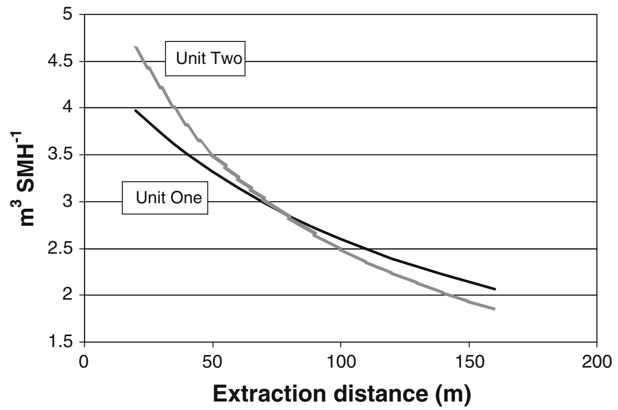

Fig. 1 Yarding productivity as a function of yarding distance. *Note:* productivity calculated for a lateral yarding distance of 15 m, and by including all delay time except for the time taken by preparation, set-up and dismantling

power available for unit one, drawn from the PTO of an 80 kW farm tractor. On the contrary, unit two had to rely on its 7 kW engine for both hoisting and travelling, and power was certainly a limit when moving the carriage uphill to the loading point. The Miniliner carriage can travel faster, but this led to the rapid overheating of both engine and hydraulic fluid during pre-study tuning tests.

Unit two offered two important advantages over unit one. The self-propelled carriage could be moved along the skyline during loading at the touch of the remote, which allowed easy maneuvering around obstacles. When the carriage of unit one was to be moved along the skyline to clear an eventual obstacle during lateral yarding, the load had to be released, the hook hauled in and the hydraulic clamping block moved further up or down the skyline, after releasing the clamp. Such maneuver was laborious and time-consuming. Secondly, the drop-line of the Miniliner carriage was paid out by the carriage engine, without any need for the operator to pull the rope off the winch, against the rope's own weight. This feature was much appreciated by the operators, who reported a lower perceived strain and fatigue. Their subjective remarks are fully compatible with the findings of published scientific studies investigating this very topic (Sripraram and Tasaka 1999).

It is important to stress that the goal of the test was not to compare the two units under the same work conditions, but rather to evaluate their potential as a complementary set of equipment for application to small-scale forestry. A direct comparison drawn between the two units could only be warranted if the working conditions had been the same.

It would be worth attempting to compare the performances of the mini-yarders tested in this study with light tower yarders reported in bibliography, designed for intense professional utilization and about 5 times as expensive to acquire. In a very recent study, Zimbalatti and Proto (2009) report the productivity of three different light tower yarders, used for hauling firewood in Southern Italy. It seems that light tower yarders are generally used for longer hauls (200–300 m) than those observed in our tests. For this reason, the productivities reported by Zimbalatti and Proto are very similar to those we have found for the mini-yarders; in the range between 1.5 and 2.5 m^3, including delays, set-up and dismantling. Apparently, mini-yarders can compete with light tower yarders over short extraction distances: when distance increases, the heavier load capacity of the light tower yarder allows for a better performance. On the other hand, the limited payloads recorded in our study may depend more on the characteristics of the silvicultural treatment than on machine capacity. The fact that none of the regression analyses detected payload size as a significant independent variable means that the maximum loads of about 0.4–0.5 m^3 hauled by both mini-yarders were below the capacity of these machines. Therefore, the comparably lighter average load of 0.2 m^3 recorded for both units must have derived from reasons other than machine capacity, and namely the difficulty of assembling a large enough load in a thinning, where the harvest is scattered and residual trees prevent collecting much wood from any single spot. If the tests would have been conducted in a clearcut, as it was with the Calabrian study, it is likely that the average payload assembled by both miniyarder would have not fallen much below the 0.5 m^3 quoted for the light tower yarders.

In conclusion, mini-yarders seem to offer a good solution to wood extraction on steep terrain, competitive with animal and winch logging in terms of productivity, cost and operator comfort.

References

Baldini S, Spinelli R (1987) Logging with mules in Central Italy. Draught Anim News 7:3–7 CTVM, University of Edinburgh

Becker P, Jensen J, Meinert D (2006) Conventional and mechanized logging compared for Ozark hardwood forest thinning: productivity, economics, and environmental impact. Nort J App For 23:264–272

Bergstrand KG (1991) Planning and analysis of forestry operation studies. Skogsarbeten Bull 17:63

Björheden R, Apel K, Shiba M, Thompson MA (1995) IUFRO forest work study nomenclature. Swedish University of Agricultural Science, Dept. of Operational Efficiency, Garpenberg 16 p

Bliss J, Kelly E (2008) Comparative advantages of small-scale forestry among emerging forest tenures. Small-scale For 7:95–104

Cantiani P, Spinelli R (1996) Conversion to high forest of Turkey oak coppices. Annali dell'Istituto Sperimentale per la Selvicoltura 27:191–200 Arezzo, Italy

De Lasaux M, Hartsough B, Spinelli R, Magagnotti N (2009) Small parcel fuel reduction with a low-investment, high-mobility operation. West J Appl For 24:205–213

Dubey P (2008) Investment in small-scale forestry enterprises: a strategic perspective for India. Small-scale For 7:117–138

Eroglu H, Acar H, Sinan H, Ozkaya M, Tilki F (2007) Using plastic chutes for extracting small logs and short pieces of wood from forests in Artvin, Turkey. Build Environ 42:3461–3465

Gullberg T (1995) Evaluating operator-machine interactions in comparative time studies. Int J For Eng 7:51–61

Hartsough B (2003) Economics of harvesting to maintain high structural diversity and resulting damage to residual trees. West J Appl For 18:133–142

Hartter J, Boston K (2008) Consuming fuel and fuelling consumption: modeling human caloric demands and fuelwood use. Small-scale For 7:1–15

Hoesch M (2003) Technology development as driving force for rationalization in Forest Companies. In: Proceedings of Austro 2003 "High Tech Forest Operations for Mountainous Terrain", October 5–9, Schlaegl, Austria, 11 p

Huyler N, LeDoux C (1997) Cycle-time equation for the Koller K300 cable yarder operating on steep slopes in the Northeast. Res. Pap. NE-705, USDA Forest Service, Northeastern Forest Experiment Station 4 p

Kittredge D, Mauri M, McGuire E (1996) Decreasing woodlot size and the future of timber sales in Massachusetts: when is an operation too small? Nort J Appl For 13:96–101

Kofman P (1995) Siwork 3: user guide. Danish Forest and Landscape Research Institute, Vejle 37 pp

Lien G, Størdal S, Baardsen S (2007) Technical efficiency in timber production and effects of other income sources. Small-scale For 6:65–78

Lyon JP, Cubbage FDW, Greene WD (1987) Systems for harvesting small forest tracts. ASAE Paper No. 87-1565. St. Joseph

Miyata ES (1980) Determining fixed and operating costs of logging equipment. General technical report NC-55. Forest Service North Central Forest Experiment Station, St. Paul 14 pp

Niskanen A, Lunnan A, Ota I, Blatner K, Herbohn J, Bull L, Ferguson I, Hickey G (2007) Policies affecting forestry entrepreneurship. Small-scale For 6:233–255

Nosenzo A (2008) Tavola di cubatura a doppia entrata per i cedui di faggio del Piemonte (Double-entry tariff table for the beech coppice stands of Piedmont). Forest 5:227–232

Rickenbach M, Steele T (2006) Logging firms, nonindustrial private forests, and forest parcelization: evidence of firm specialization and its impact on sustainable timber supply. Can J For Res 36:186–194

SAS Institute Inc (1999) StatView reference. SAS Publishing, Cary. pp 84–93. ISBN-1-58025-162-5

Scott A (1973) Work measurement: observed time to standard time. In: Wittering, W (ed) Work study in forestry. Forestry Commission Bulletin, vol 47, pp 26–39

Shresta S, Rummer R, Dubois M (2005) Utilization and cost of log production from animal logging operations. Int J For Eng 16:167–180

Spinelli R, Visser R (2009) Analyzing and estimating delays in wood chipping operations. Biomass Bioenerg 33:429–433

Spinelli R, Magagnotti N, Nati C (2009) Options for the mechanized processing of hardwood trees in Mediterranean forests. Int J For Eng 20:39–44

Sripraram D, Tasaka T (1999) The ability of a carriage developed for a mobile tower yarder: a comparison of the hauling force and walking time in a line pulling operation. J For Res 4:255–259

Stampfer K, Daxner P, Visser R (1998) An alternative cable system: self propelled carriages. Liro Forest Solutions Technical Note. TN-46. 3 pp

Toms C, Dubois M, Bliss J, Wilhoit J, Rummer B (2001) A survey of animal-powered logging in Alabama. South J Appl For 25:17–24

UK Forestry Commission (1995) Terrain classification. Technical Note 16/95, 5 pp

Väätäinen K, Asikainen A, Sikanen L, Ala-Fossi A (2006) The cost effect of forest machine relocations on logging costs in Finland. For Studies 45:135–141

Wang L (1997) Assessment of animal skidding and ground machine skidding under mountain conditions. J For Eng 8:57–64

Zeĉić Z, Krpan A, Vukuŝić S (2005) Productivity of Holder 870 tractor with double drum winch Igland 4002 in thinning beech stands. Croat J For Eng 26:49–56

Zimbalatti G, Proto A (2009) Cable logging opportunities for firewood in Calabrian forests. Biosist Eng 102:63–68